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ABSTRACT

Helical wire inserts and a new type of perforated strip-type inserts were inserted into tubes of 9.52mm outer diameter to enhance R-22 flow boiling heat transfer performance in the tubes of louvered fin-and-tube heat exchangers. The total heat transfer capacity of the evaporator with inserts was experimentally compared with that of the evaporator without inserts under the same operating condition. The experiments were carried out in Air-conditioning and Heat Exchangers Laboratory directly under our incorporation. The experimental results show that the total heat transfer capacity of the evaporators with perforated strip-type inserts were 20% higher than that of the corresponding evaporators with grooved or smooth tubes without inserts when the outlet superheat was 2℃, however the capacity of the evaporator with helical wire inserts was a little lower than that of the corresponding evaporator with grooved tubes without inserts.

1. INTRODUCTION

The design of efficient heat exchangers in air-conditioning industry is necessary to energy conservation. The airside of fin-and-tube heat exchangers usually has been augmented by various extended surfaces, such as plain fin, waved fin, louvered fin and slit fin, etc, and the tube side by grooved surfaces. To improve the tube side heat transfer performance further, the augmentative technique of installing inserts inside tubes may be a choice.

A review of the existing literature revealed that fundamental investigations on various inserts, such as twisted tape, helical wire or spiral spring, has been carried out to study the augmentative effect of two phase flow heat transfer coefficient during refrigerants flow inside tube. Agrawal et al (1998) reported the use of helically coiled wires increased the R-22 condensing heat transfer coefficients by 100% above the horizontal plain tube. Lan et al (1997) found the heat transfer coefficients for R-113 flow boiling in vertical tubes with two wire helix geometries tended to be below those observed in a vertical smooth tube for similar conditions. Ma et al (2004) found that only for temperature difference greater than 10K did the addition of the wire insert improve the heat transfer performance for R-113 film condensation in a vertical internally finned tube. Hsieh et al (2003) investigated heat transfer coefficients for R-134a and R-600a in a horizontal smooth tube with vertically positioned perforated strip-type inserts. The experiment results showed that the heat transfer performance was improved up to 2.5 for a 96 perforated holes enhanced tube. However, little literature related to practical application investigation exists.

The present investigation was undertaken to study the augmentative effect of the helical wire and the new type of perforated strip-type insert in the fin-and-tube evaporators during R-22 flow boiling inside smooth or grooved tubes.

2. EXPERIMENT SETUP AND PROCEDURE

2.1 Test facility

The experiments were carried out in Air-conditioning and Heat Exchangers Laboratory directly under our incorporation, consisting of an Air Enthalpy Method Calorimeter and a R-22 supply facility. The lab is equipped with automatic control devices and high precision metrical instruments, which was designed and constructed by two professional institutes and is the first one running in China.

General tests of the evaporator, condenser and capillary of domestic air-conditioning can be carried out on the R-22 supply facility together with the calorimeter. There are two control modes for evaporator test in the R-22 loop: the controlled parameters are (1) the expansion valve inlet pressure and subcooling, the evaporator inlet or outlet pressure (or their average value) and the outlet superheat or (2) the mass flow rate through the evaporator.

2.2 Test section

The outline of the plate-type fin-and-tube heat exchangers (only one row in streamwise) with 468 louvered fins and 8 U-type tubes is sketched in figure 1 and figure 2, respectively, different in flow path. The louvered fin pitch is 1.4mm, and the transverse tube pitch and longitudinal pitch is 25.4 mm and 22 mm, respectively. Hence, the upwind face's size is 654 mm×406 mm and the streamwise size is 22 mm.

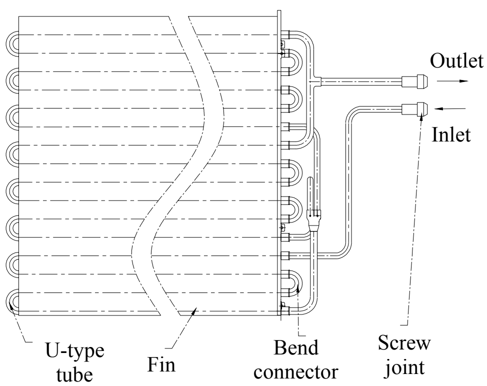

Figure 1: The outline of evaporator with flow path 1

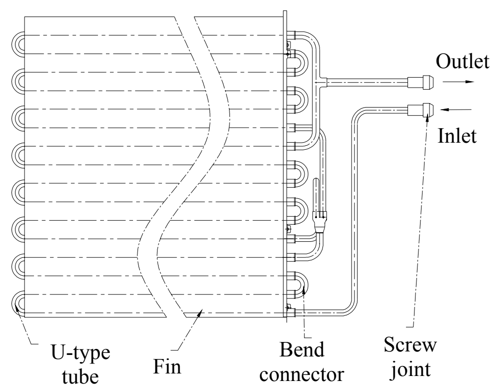

Figure 2: The outline of evaporator with flow path 2

Table 1: The geometric parameters of the tubes (unit: mm)

Tube	Inside surface	O.D.	Average thickness	Thinnest thickness	Fin height	Groove width	Apex angle	Grooves
G	Grooved	9.52	0.36	0.3	0.2	0.22	55	60
S	Smooth	9.52	0.35	-	-	-	-	-

Table 2: The geometric parameters of the perforated strip-type inserts (unit: mm)

Tube	I.D.	dD^*	Insert	t	w	d	m	n	L	Holes
G	8.52	≈0.3	GP20	1	8.6	5	10	20	600	30
			GP40	1	8.6	5	20	40	600	15
S	8.82	≈0.3	SP20	1	8.9	5	10	20	600	30
			SP40	1	8.9	5	20	40	600	15
			SP60	1	8.9	5	30	60	600	10

Note: dD^* is the increment in tube radial direction by mechanical expansion.

Two kinds of tubes with different inside surfaces are chosen to study the augmentative effect the helical wire and the new type of perforated strip-type insert. The geometric parameters of the grooved tubes (G) and the smooth tubes (S) are listed in table 1, and the helical wire (material: stainless steel) and the perforated strip-type insert (material: brass) in table 2 and table 3, respectively. Geometry of the latter is sketched in figure 3.

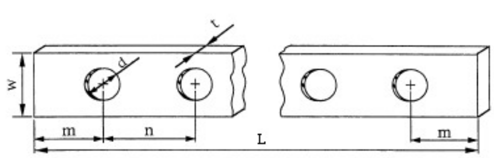

Figure 3: The geometry of the perforated strip-type inserts

Five evaporators were tested with or without inserts inside the tubes. The combinations are listed in table 4. The evaporators were fully installed except for the evaporator 5# which was installed only six helical wires upstream.

Table 3: The geometric parameters of the helical wires (unit: mm)

Tube	I.D.	Insert	Diameter	Pitch	Coil diameter	Length
G	8.52	GC0.5×1.5	0.5	1.5	8.2	650

Table 4: The experimental combinations of the evaporators with or without inserts

Serial No.	1#	2#	3#	4#	5#
Tube	S	S	G	G	G
Insert	SP40, empty	SP20, SP60	GP40, empty	GP20	GC0.5×1.5, empty
Flow path	Figure 1	Figure 1	Figure 1	Figure 1	Figure 2

2.3 Test procedure

The purpose of installing inserts inside tubes was to improve the heat transfer rate of the fin-and-tube heat xchangers, in view of practical application. The test method for comparison was established based on the following analysis.

The heat transfer rate of a fin-and-tube evaporator can be expressed in the form of thermal resistance as follows,

$$Q_0 = \frac{\Delta T_m}{\left(R_{A,i} + R_{A,a}\right)/L_h} \tag{1}$$

where, ΔT_m, logarithmic mean temperature difference between air flow and refrigerant flow; L_h, efficient tube length for heat transfer; $R_{A,i}$, and $R_{A,a}$, thermal resistance per unit length of tube side and airside, respectively.

The thermal resistance of tube side and airside can be expressed as follows, respectively,

$$R_{A,i} = \frac{1}{\alpha_i A_i} \tag{2}$$

$$R_{A,a} = \left\{(\alpha_a \cdot \xi)\cdot\left[\eta_f \cdot \frac{2N\left(s_p \cdot s_n - \pi \cdot d_o^2/4\right)}{s_f} + \frac{\pi\left(d_o + 2\delta_f\right)\left(s_f - \delta_f\right)}{s_f}\right]\right\}^{-1} \tag{3}$$

where, α_i, heat transfer coefficient inside tube; A_i, surface area per unit length inside tube; α_a, convection heat transfer coefficient of airside; ξ, wet efficiency contributed to mass transfer; η_f, fin efficiency; s_f, fin pitch; δ_f, fin thickness; s_p, transverse tube pitch; s_n, longitudinal tube pitch; d_o, tube outside diameter; N, number of longitudinal tube rows.

From Eq. (1) ~ (3), it can be seen that the heat transfer rate of an evaporator with its geometry prescribed mainly depends on temperature difference between air flow and refrigerant flow, efficient length of tube affected by outlet superheat of refrigerant, wet efficiency affected by inlet relative humidity of air flow, heat transfer coefficient of airside affected by air flow velocity and that of tube side. The tube side heat transfer coefficient mainly depends on mass flow rate and inlet mass flow fraction of gas in addition to installing inserts or not. Since the mass flow rate and the outlet superheat of refrigerant can not be controlled in the same time, the latter is chosen to be controlled according to practical application.

Based on the foregoing analysis, the operating condition was specified as follows,

Refrigerant: R-22
Inlet dry bulb temperature: 27 ℃
Inlet wet bulb temperature: 19 ℃
Volume flow rate of air: 800 m^3/h
Inlet absolute pressure of expansion valve: 1.8 MPa
Inlet subcooling of expansion valve: 8 ℃
Average evaporation absolute pressure: 0.641 MPa
Outlet superheat of refrigerant: 2 ℃, 5 ℃, 10 ℃.

3. RESULTS AND DISCUSSION

Figure 4 to figure 6 show the total heat transfer capacity varying with the outlet superheat of the evaporators. It can be seen from the three figures that the tested evaporators' heat transfer rate decreases with the outlet superheat increasing.

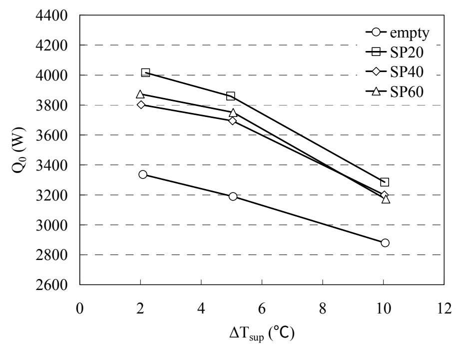

Figure 4: Heat transfer rate of 1# and 2# evaporators with perforated strip-type inserts inside smooth tubes

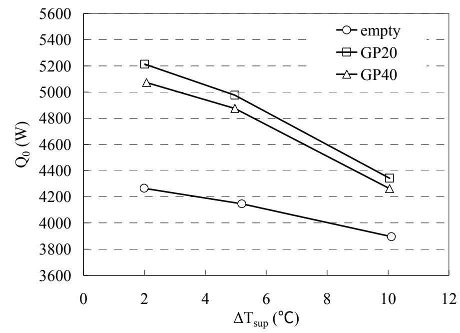

Figure 5: Heat transfer rate of 3# and 4# evaporators with perforated strip-type inserts inside grooved tubes tube

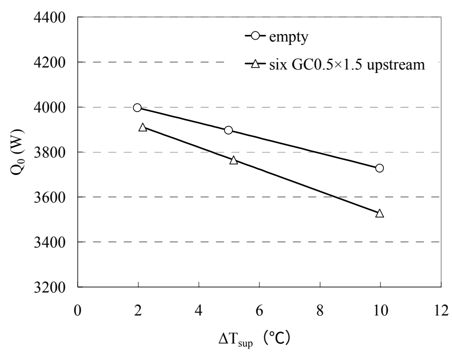

Figure 6: Heat transfer rate of 5# evaporator with six helical wires inside grooved tubes upstream

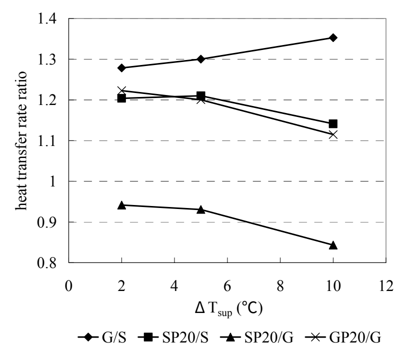

Figure 7: Heat transfer rate ratio of the evaporators with perforated strip-type inserts inside smooth or grooved tubes

Figure 4 and figure 5 show that the perforated strip-type inserts can not only improve the heat transfer rate of the evaporator with smooth tubes but also improve that of the evaporator with grooved tubes. It also can be seen from the two figures that the heat transfer rate almost increases with the hole pitch decreasing, as expected, except for insert SP40 and insert SP60 which are in different evaporators. The unexpected trend was likely caused by the individual difference between the two evaporators.

The enhanced heat transfer mechanism of the perforated strip-type inserts may be explained as the following two reasons. On one hand, the perforated strips change the gas velocity profile of one peak into the one of two peaks, thus increases the interfacial velocity gradient and the average velocity of the liquid film flowing attached to the tube inside wall, hence the heat transfer performance of tube side is improved; on the other hand, the existing holes in the strips disturb the two phase flow, and the disturbance frequency increases with the hole pitch decreasing, thus the heat transfer performance of the tube side is improved further and appears the increasing trend when the hole pitch decreasing.

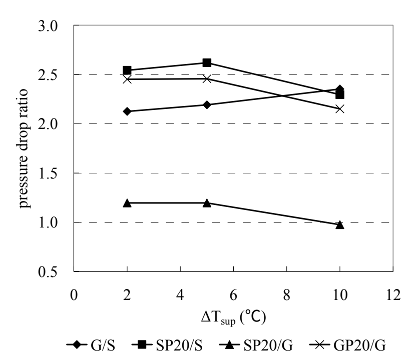

Figure 8: Pressure drop ratio of the evaporators with perforated strip-type inserts inside smooth or grooved tubes

Figure 6 shows that the heat transfer rate of the evaporator with six helical wire upstream installed in tubes, however, decreases in comparison with that of the same one with empty tubes. The installed coils with diameter of 0.5 mm maybe hinder the flow of the liquid film, thus increase the local film thickness and deteriorate the local heat transfer performance.

Figure 7 and figure 8 show the heat transfer rate ratio and the pressure drop ratio varies with outlet superheat, respectively. The legend G/S in figure 7 denotes the heat transfer rate of the evaporator with empty grooved tubes in comparison with that of the one with empty smooth tubes, the rest may be deduced by analogy. In comparison with the empty evaporator, the heat transfer rate ratio is about 1.1 ~ 1.2 for both smooth and grooved tubes installed the perforated strip-type inserts with the hole pitch of 20 mm , under the operating condition, but the pressure drop ratio is about 2.2 ~ 2.5. The heat transfer rate ratio is 1.28 ~ 1.35 for empty grooved tubes being compared with empty smooth tubes, and the pressure drop ratio is 2.1 ~ 2.4 in the same case. In comparison with the empty grooved tubes, the heat transfer rate ratio is lower than unit for the smooth tubes installed the 20 mm hole pitch inserts, but the pressure drop ratio is almost higher than unit. Therefore, the all-around performance, in view of heat transfer performance and pressure drop, for the smooth tubes with the 20 mm hole pitch inserts is lower than that for the empty grooved tubes.

4. CONCLUSIONS

The heat transfer performance and pressure drop of the helical wires and the new type of perforated strip-type inserts with several hole pitches installed in five fin-and-tube evaporators during R-22 flow boiling inside tubes were experimentally investigated. Under the operating condition presented in this paper, the following conclusions can be drawn:

(1) The perforated strip-type inserts installed vertically in smooth tubes or grooved tubes can obviously improve the heat transfer rate of the evaporators, but the helical wires installed in grooved tubes slightly reduce the heat transfer rate of the evaporate.

(2) In comparison with the empty evaporator, when the outlet superheat is 2℃, the heat transfer rate is improved up to 20% for both smooth and grooved tubes installed the perforated strip-type inserts with the hole pitch of 20 mm, but the pressure drop increases about 150%.

(3) Keeping the outlet superheat constant, the heat transfer rate of louvered fin evaporator is improved about 30% for empty grooved tubes being compared with empty smooth tubes, and the pressure drop increases about 120% in the same case. The all-around performance, in view of heat transfer performance and pressure drop, for the smooth tubes with the 20 mm hole pitch inserts is lower than that for the empty grooved tubes.

(4) The heat transfer rate of the five evaporators tested decreases when increases the outlet superheat, therefore, the outlet superheat of an evaporator should be kept as low as possible to make full use of the evaporator's potential capacity in practical application.

REFERENCES

Agrawal, K. N., Kumar, A. et al, 1998, Heat Transfer Augmentation by Coiled Wire Inserts During Forced Convection Condensation of R-22 Inside Horizontal Tubes, *Int. J. Mutiphase Flow*, vol. 24, no. 4: p635-650.

Ma, X. H., Briggs, A., Rose, J. W., 2004, Heat Transfer and Pressure Drop Characteristics for Condensation of R-113 in a Vertical Micro-finned Tube With Wire Insert, *Int. Comm. Heat Mass Transfer*, vol. 31, no. 5: p619-627.

Lan, J., et al., 1997, Two Phase Flow Patterns and Boiling Heat Transfer in Tubes Containing Helical Wire Inserts Part I--Flow Patterns and Boiling Heat Transfer Coefficients, *Enhanced Heat Transfer*, vol. 4, no. 4: p269-281.

Hsieh S. S., Jang K. J., Tsai, H. H., 2003, Evaporative Characteristics of R-134a and R-600a in Horizontal Tubes with Perforated Strip-type Inserts, *Int J Heat & Mass Transfer*, vol. 46: p1861-1872.